Sustainability Science and Technology

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EDITORIAL

Sustainability Science and Technology in 2024 and beyond: equitable publishing aligned with United Nations' Sustainable Development Goals

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Keywords: sustainability, science, technology

IOP Publishing is a society-owned scientific publisher and is central to the Institute of Physics, a not-for-profit society. In November 2023, IOP Publishing introduced *Sustainability Science and Technology (Sus Sci Tech)*, a journal focused on fundamental, translational, and practical aspects of sustainability. Professor Jonas Baltrusaitis was selected as the inaugural Editor-in-Chief and will be working with the outstanding researchers from the Editorial Board who are co-authors of this editorial to make this journal a leader in sustainability science and technology research. Together, this *Sus Sci Tech* team will use their diverse background and expertise to provide insight, vision and guidance to the journal and its authors.

The journal covers research related to all aspects of sustainability as defined in this editorial. It seeks diverse contributions from chemistry, physics, environmental science, engineering, and system design, envisioning a future where these disciplines are constantly evolving, propelled by global challenges and technological innovations. Of particular interest are experimental research and theoretical/philosophical aspects that focus on new insights into fundamental concepts of sustainability, novel materials, products, systems, and designs leading to improved sustainability of society, and validation of their practical applications and impacts. The journal places a strong emphasis on promoting equitable and inclusive publishing practices across various academic disciplines, regions, and demographic groups. This underscores the dedication of the journal to fostering diversity and inclusivity.

The journal promotes interdisciplinary and innovative research and facilitates the integration of diverse academic approaches and methodologies, acknowledging that the crucial insights needed to advance sustainability often sit at the nexus of many disciplines. It also highlights the importance of using sustainability metrics in research. The journal takes a wider view of sustainability, considering social, economic, and environmental aspects, and seeks to address both current and future challenges in the field, while differentiating itself from exclusively green chemistry-focused journals. Where these disciplines outside the sciences can contribute to advancing sustainable science and technology, their contributions will find a home in this journal. This positions the journal at the forefront as a platform for advanced, interdisciplinary sustainability research.

Sustainability Science and Technology complements established IOP Publishing journals that cover energy and environmental research, including *Journal of Physics: Energy, Progress in Energy,* and *Environmental Research Letters*. Authors who submit to *Sustainability Science and Technology* benefit from a wide transfer network which helps them to find the most suitable home for their research, including community journals such as *Engineering Research Express, Materials Research Express,* and *Environmental Research Communications*.

Definition of *sustainability* within Sus Sci Tech scope

Sustainability is defined as 'meeting the needs of the present without compromising the ability of future generations to meet their own needs' [1] and research works published should account for this concept. This principle is embodied in the foundations of green chemistry [2] and green engineering [3] as well as the concept of a circular economy, intended to mimic the renewing processes of nature. The manuscripts submitted should be cognizant that a green approach or the use of green materials does not always constitute sustainable development. For these reasons, the work published will consider concepts that not only include but also extend beyond green chemistry and engineering. This includes interdisciplinary approaches, innovative methods and new article types that support sustainable development, integrating diverse knowledge domains within all three pillars of sustainability (societal, economic, and environmental), and recognizing the importance of ensuring a healthy ecosystem to symbiotically support both human and non-human life. All three pillars are embodied in the pictorial symbol of the journal embodying circularity as a key concept of sustainable development.

Guidelines for authors:

Introduce the reader early to the concepts, theories, definitions, or particular (sub)areas of sustainability that the manuscript addresses; for example, this can be highlighted in the abstract of the manuscript.

Suggested reading:

Getting the terms right: green, sustainable, or circular chemistry? [4].

Relevance to UN Sustainable Development Goals (SDGs)

Sus Sci Tech solicits research publications that aim to address one or more of the UN SDGs classified and clustered according to Lucas and Wilting [5].

The scope of the journal includes:

- The planetary boundary of natural resources that govern safe operating space for humanity;
  - examples include air, water, and soil pollution, climate change, critical raw materials and nutrients, nutrient cycling, emerging contaminants, their toxicity and remediation, freshwater and saltwater use, depletion, and pollution.
- Sustainable production and consumption of goods;
  - bio, organic and inorganic synthesis, various forms of energy harvesting, infrastructure, product and process design, use, disposal/decommission, and recycling. Examples include biorefineries, the built environment and construction, carbon capture storage, CO_2 conversion, energy carriers, energy harvesting, electronics production and decommissioning, food and agricultural systems and technology, pharmaceutical synthesis and end-of-life, plant and biota nutrients, waste reduction, and utilization.
- Equitable distribution of goods and services;
  - examples include logistics and supply chain management, systems engineering, life cycle assessment, predictive computing, the circularity of (bio)economy, and systems design.
- Poverty and human well-being;
  - technologies, processes, and products that drive poverty reduction, and educational and gender inequality within and between the communities and countries.
- The relationship between growth and sustainability;
  - analyses highlighting synergies, but also tensions between economic and sustainable growth.

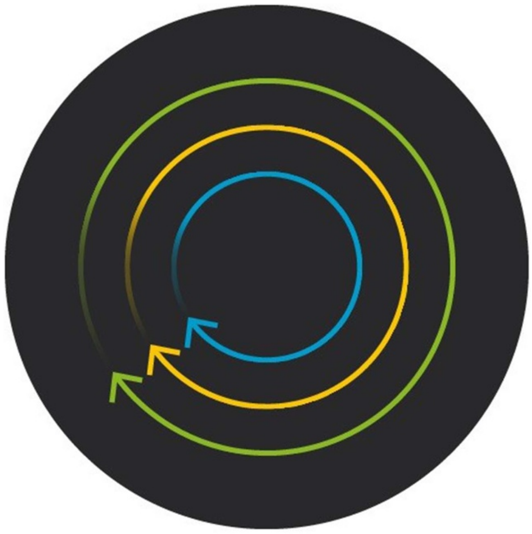

Figure 1. A pictorial symbol of *Sus Sci Tech* with circularity as a key concept underpinning three pillars of sustainability (societal, economic, and environmental).

Guidelines for authors:
In their submission letters, authors are encouraged to make explicit reference to how their work links to the SDGs in their abstract or introduction, ensuring that the resolution(s) proposed in their work does not challenge the resolution of other SDGs.

Suggested reading:
United Nations, The 17 SDGs [6].

1. Themes of the *Sus Sci Tech* scope

Re-envisioning sustainability science and sustainability technology now and in the future using planetary boundaries. Our vision for the future of sustainability science and technology involves continuously adapting and innovating in response to global challenges and technological advancements (figure 1). We see this field as an evolving landscape as shown in figure 2, where new ideas, problems, their solutions and overall focus areas emerge and adapt over time, guiding the emergence of a more sustainable future. **Agriculture, Energy & Transport** including chemical production and **Construction** account for key areas contributing to all planetary boundaries while we consider **Climate Response, Metrics** and **Governance and Social** clusters strongly overlapping or even integral across the fabric of the sustainability discipline. The domain of sustainable **Construction** has been of particular interest in the last few decades with an emphasis on green buildings and low-waste construction concepts [7]. While largely outside of the conventional concepts of sustainable chemistry and chemical engineering, it has a profound impact on the circular economy and UN SGDs [8].

The nature of sustainability science and technology is multidisciplinary and interdisciplinary, positioned to attract a wide readership and contributions from different research areas, including chemistry, physics, environmental, chemical, biomolecular, materials engineering, and system design. The opportunities of sustainability-focused research to benefit the broad community at large are unparalleled, representing critical infrastructures and exploring the synergies between them, for the future of our planet and human society [9].

Guidelines for authors:
If possible, define boundaries where specific products or processes will operate, reside in, or affect. Highlight where systems integration can bring greater benefits.

Suggested reading:
The planetary boundary concept [10].

Transformations, transitions and change in energy in climate research [11]. Understanding the Water-Energy-Food Nexus [12].

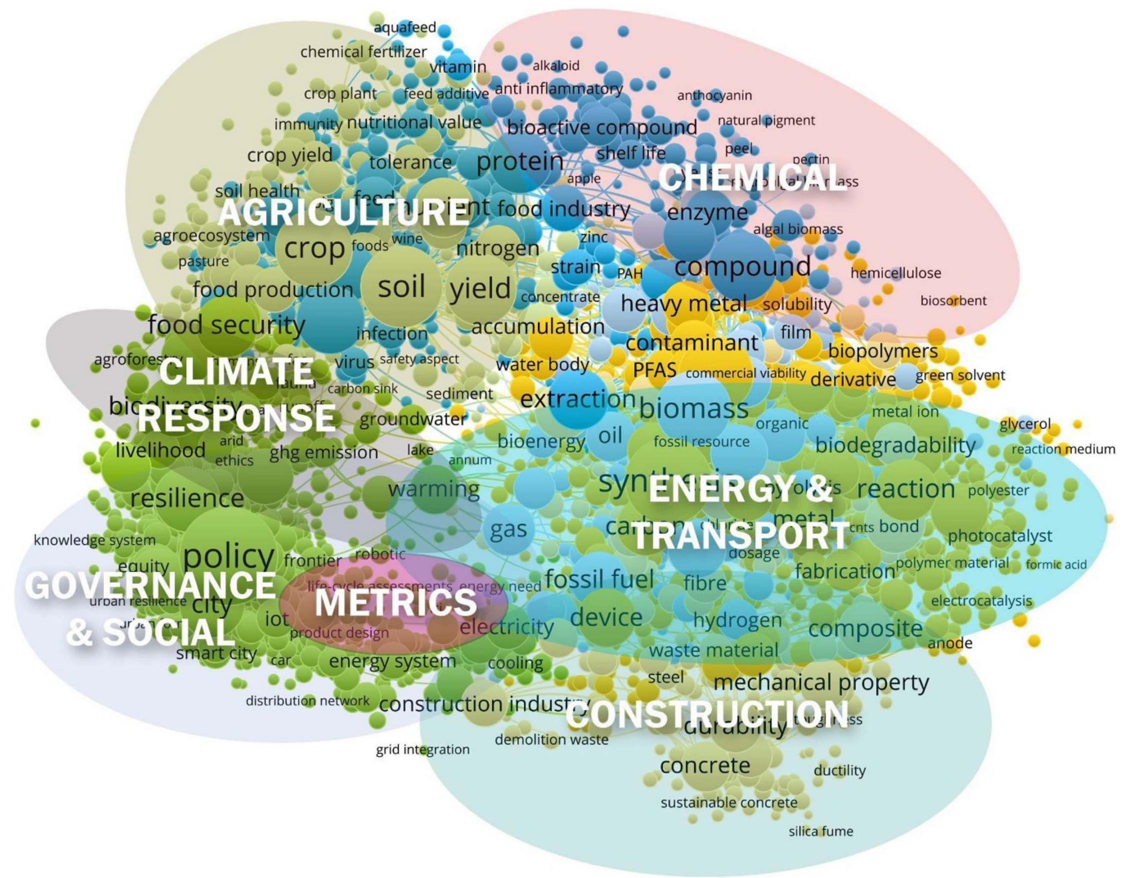

Figure 2. Web of Science search results (accessed 26 January 2024) of the reviews in the last 5 years on the term ‘sustainability’ with the minimum threshold of occurrences per term set to five. Visualized using VOSviewer v 1.6.16.

Re-defining sustainability impacts and priorities. Sus Sci Tech’s approach to covering all SDGs involves integrating a wide range of topics, reflecting both local and global concerns. We aim to provide a comprehensive platform that addresses the interconnectedness of these goals, ensuring an inclusive perspective on sustainability. The importance of a holistic view is essential—while greenhouse gas (GHG) emissions are extremely relevant to the modern *zeitgeist* of sustainability, they are not the only factor to consider and their exclusive focus may hide or detract from the significance of other sustainability aspects.

Guidelines for authors:
Recognizing that it is challenging to cover all aspects of sustainability, submissions must take as holistic an approach as possible, considering the wider impacts and identifying trade-offs between resolutions towards multiple SDGs.

2. Relevant editorial concepts of emphasis

Re-defining how sustainability is conveyed in scientific publications. The journal welcomes innovative formats of scientific presentation, such as infographics, for effectively communicating sustainability concepts and introducing new styles and forms of presenting research and ideas.

Guidelines for authors:
Consider how your work can be more effectively communicated or summarized, using visualization and dynamic techniques. Sometimes an infographic, with well-researched data, can be an impactful way to illustrate the main issues, interactions, or complexities of a particular topic. While authors are encouraged to creatively consider the visual content of their manuscripts, the link to dynamic websites and videos can also be provided as a reference with the date of access.

Suggested reading:
Preparing scientists for a visual future [13].

Ensuring just and equitable publishing across disciplines, geographies, and demographics. Given the explosive growth and interest in technological innovations associated with sustainability, a challenge arises: how to ensure their successful translation toward commercial scale to address practical needs? Translational sustainability research would require committed efforts from academia, industry, and government agencies. Moreover, over the years, significantly increased community awareness about the need for a sustainable future provides our journal excellent opportunities to reach and influence non-scientific broad communities, such as future generations (K-12 students) and people from under-served areas. These opportunities will be particularly compelling especially considering the open-access nature of our journal, allowing us to directly interact with broad communities while focusing on a critical societal topic. To achieve equitable publishing, our journal is committed to embracing a diverse range of scholarly voices from various disciplines, geographical regions, and demographic backgrounds. We aim to create a platform that reflects many perspectives, ensuring that our content is as diverse and inclusive as the global community it serves.

Guidelines for authors:
Including contributor role taxonomy (CRediT) statement in the publication clearly outlining the contributions of each author.

The open access charge (APC) is waived until 2027. Check if you further qualify for reduced or waived APC before submission
(https://publishingsupport.iopscience.iop.org/questions/paying-for-open-access/).

Suggested reading:
CRediT website (https://credit.niso.org/). Equity for open-access journal publishing [14].

3. The importance of quantitative metrics for sustainability science and technology

Society has a growing interest in understanding the sustainability implications of scientific discoveries and technological innovations. Readers can contextualize research findings by comparing established metrics across studies, which is key to attracting a broad audience of scientists and researchers. Sustainability metrics [15], in particular, help readers understand novel studies' efficiency, environmental, economic, and social implications. Many sustainability metrics have become common knowledge. Emerging metrics can strengthen arguments toward novel techniques and perspectives. Studies that define new metrics through fundamental theory and a broad set of applied examples have strong potential to steer future research directions. We encourage authors to provide sustainability metrics that appeal to broader societal goals. These metrics can be qualitative or quantitative. Some studies may need more data or resources to provide quantitative sustainability metrics. Authors should reference relevant literature for related sustainability metrics in these cases.

Advances that improve the efficiency of resource, energy, and exergy use [16] can report percentage improvements in efficiency, the reduction in non-renewable resource use, or other relevant metrics. Studies that reduce environmental and ecological impacts can report the percentage reduction in environmental and ecological impacts, the ability to utilize low carbon footprint and waste resources, or improvements to ecosystem services and environmental health, among other metrics [17]. Developments that improve economic and social impacts [18] can report the percentage increases in economic productivity, social benefits, human well-being, or similar metrics.

Sustainability metrics should refer to a well-established baseline. Well-established baselines include practices and technologies familiar to a significant portion of the general population or relevant scientific community. These baselines are often referenced in many articles or by authoritative sources. Using commonly known metrics like global warming potential and the gross domestic product is encouraged. When employing common metrics, the article should briefly describe the metric and cite an authoritative reference. Novel metrics should be described in detail, and authors should justify not using a more common metric. These articles should include enough information to reproduce the calculation of the metric. Authors are encouraged to emphasize quantitative sustainability metrics in the abstract and highlights of the article.

Guidelines for authors:
Authors are encouraged to use quantitative and qualitative sustainability metrics to strengthen the relevance and impact of their articles. Using novel metrics is welcomed when accompanied by a detailed explanation and applied examples. These metrics should be highlighted in the article.

Suggested reading:
Sustainable engineering: Drivers, metrics, tools, and applications [19].

The author initiated special issues (SI). The editorial board will be soliciting special issues but authors can share a well-described plan for SI with the Editor-in-Chief for approval and commencement. There will also be an open opportunity to submit reviews and perspectives on all aspects that *Sus Sci Tech* covers with the approval of the Editor-in-Chief. Authors are also encouraged to reach out to the editorial board members to commence new thematic SIs although it is not mandatory.

Guidelines for authors:
Authors can submit their perspectives and reviews to the open call where they will be screened for suitability before review. Authors are also encouraged to conceptualize thematic SIs within their field with or without engaging the editorial board. Finally, authors are encouraged to peruse the @IOP_SSTECH handle when sharing their works on social media.

4. The editorial board envisioned focus areas of *Sus Sci Tech*

Sustainable agriculture
Achieving the United Nations' SDGs fundamentally depends on the implementation of sustainable agriculture practices. As a core element of sustainable science and technology, the integration of agriculture with sustainable practices, especially in major commodities (corn, soybean, etc) is crucial in ensuring food security, preserving natural resources, and mitigating environmental impact. It includes animal production and its effects on the food chain and environment (e.g., methane emission and water pollution). This section underscores the importance of sustainable agriculture in the journal's mission and its alignment with the SDGs.

Importance of sustainable agriculture. *Resource Conservation* focuses on soil health and water efficiency, aiming to minimize soil degradation and optimize water use. Practices such as water resource management, soil erosion control, and integrated pest management play crucial roles in preserving ecosystems and enhancing biodiversity. *Reducing Environmental Impact* involves limiting the use of synthetic fertilizers and pesticides, thereby decreasing pollution and GHG emissions [20]. Practices such as agroforestry, sustainable pasture management, and organic farming are important for protecting the environment. However, the vision of sustainable agriculture is not limited to the implementation of these emerging practices, but it includes technologies possible to be applied in large-scale agriculture (commodities) and animal production to reduce their impacts. *Economic Viability* is centered on securing stable incomes for farmers and ensuring the long-term sustainability of the agricultural sector, thus leading to the development of financially sustainable agricultural systems [21]. Addressing *Food Security and Nutrition* includes enhancing productivity and using resources sustainably, particularly in areas prone to shortages, while promoting crop diversity for nutrition and health [22]. *The Socio-Economic Aspects* involve bolstering local communities through the creation of sustainable jobs and the support of local economies, contributing to poverty reduction by improving the incomes of farmers and enhancing living conditions [23]. Emphasizing *Social Responsibility* entails advocating for fairness and well-being within farming communities, which includes ensuring safe working environments, providing equitable access to resources, and fostering the development of both rural and urban areas.

Technological advancements in sustainable agriculture. Integrating technology in sustainable agriculture boosts efficiency and mitigates environmental impact. Key focus areas encompass innovative approaches such as vertical farming, hydroponics, and aquaponics, which are vital in water-scarce regions for efficient management of space and resources. The knowledge about *no-tillage production* and *integrated crop-livestock-forestry systems* should be promoted. *Precision Agriculture and Machine Learning* enhance efficiency and adaptability in soilless systems and vertical farming [24, 25]. *Advanced Irrigation Methods,* employing soil moisture sensors and atmospheric data for accurate irrigation, are crucial for sustainable water management [26, 27]. *Controlled-release fertilizers and Plant Growth Stimulants* release nutrients in a controlled manner, enhancing nutrient uptake and contributing to soil health [28]. *Agriculture 4.0*, integrating IoT and robotics, automates processes and precisely delivers nutrients, which is crucial for farming efficiency and sustainability [29, 30].

Integration with SDGs. Sustainable agriculture aids in achieving SDGs, including *Zero Hunger*, by enhancing productivity through sustainable practices; *Clean Water and Sanitation* by efficient water resource utilization and pollution reduction; *Responsible Consumption and Production* through sustainable food production methods; and *Climate Action* by the reduction of GHG emissions and carbon sequestration.

Guidelines for authors. Authors are encouraged to illustrate the contribution of their work to sustainable agricultural development, showcase innovative techniques and technologies, and merge insights from diverse fields to tackle challenges.

Suggested reading

Innovations in soil and sustainable agriculture [31].

Effective implementation of sustainable agricultural practices and policies [32], and the impact of sustainable agriculture on the environment, society, and economy [33].

5. Zero waste and sustainable waste management

Waste(water) generation is an inherent and inevitable aspect of human existence. Attaining net-zero scenarios requires that the carbon embedded in products originates from non-fossil sources (scope 3 emissions) and displaces the current reliance of the waste(water) treatment technologies on fossil-fuel-based chemicals and energy. This marks the inception of new, environmentally conscious waste(water) collection, management, and valorization technologies transitioning to sustainable feedstocks powered by renewable energy. At the heart of this transformation is the advancement of novel valorization processes and zero waste technologies that leverage biomass, carbon dioxide, recyclable materials (primarily plastics), recyclable organics and wastewater in the synthesis of both conventional platform products and innovative ones. This evolution ultimately leads to the sustainability of waste and wastewater management and is essential to safeguard water resources, soil, and air, ensuring they remain untainted by contaminants.

Importance of zero waste and sustainable waste management. *Effective waste management* is a crucial component, particularly as many waste materials are considered hazardous. Notably, addressing waste management challenges requires technological advances, paired with consumer *Social Responsibility. Smart, segregated, and efficient collection* not only prevents untreated waste and wastewater from contaminating the environment and entering the food chain but also ensures proper transport to designated treatment facilities. For example, smart, segregated, and efficient collection of plastic is crucial in adding a *circular loop for plastic* via recycling. Efficient recycling also reduces associated energy use and carbon emissions of industries, by displacing the steps required for processing virgin materials. For example, in the plastic industry, effective plastic waste recycling can significantly curtail many carbon-intensive processes, including oil cracking and refining. Segregation of organic and inorganic waste is an important element so that we can *valorize organics* through processes like composting to recover nutrients, while *recovering inorganics* can be repurposed as valuable resources. However, traditional centralized methods for composting, which requires increasing land use, and for water treatment, are becoming inadequate for handling increased loads, emerging contaminants, micro and nano plastics, and radioactive pollutants. Consequently, there is a pressing need for *decentralized and fit-for-purpose solutions* that prioritize local water treatment and distribution for specific water uses. Given the environmental concerns associated with carbon, energy, and chemical-intensive wastewater treatment methods, a transition towards energy-efficient and less chemical-intensive alternatives, i.e. *electrification of the waste(water) sector* [34], is imperative. With the ongoing shift toward cleaner electricity production, electrification emerges as a widely adopted strategy for sectors that are challenging to decarbonize. Exploring electrochemical processes as an emerging alternative becomes crucial for fit-for-purpose wastewater treatment, decontamination, resource recovery, and energy retrieval. Additionally, fostering *industrial symbiosis*, where waste from one sector becomes a valuable resource for another, plays a pivotal role in creating sustainable and interconnected solutions. Moreover, addressing the issue of CO_2 emissions from waste processes is essential. Implementing *carbon capture and utilization* techniques can help mitigate its impact on climate change and contribute to sustainability via waste CO_2-based end products.

Technological advancements in zero waste and sustainable waste management. *Advanced innovative technologies* utilize waste biomass [35–39], biowaste [40], plastics [41, 42], inorganic materials and chemicals [43, 44] and GHGs such as CO_2 [45, 46] to turn into economical products to keep the waste in the loop.

Electrified processes based on waste CO_2 *electrocatalytic CO_2 reduction* to synthesize ethylene for plastics and *electrified co-electrolysis of nitrate and CO_2 to synthesize urea. Waste Management 4.0* involves a digitized and optimized waste management system that uses intelligent solutions that improve detection accuracy, purification efficiency, accurate chemical dosage, and energy efficiency [47–49].

Integration with SDGs. Sustainable waste management aids in achieving SDG3 *Good Health and Well-Being*, SDG6 *Clean Water and Sanitation*, SDG7 *Affordable /Clean Energy*, SDG9 *Industry, Innovation and Infrastructure*, SDG12 *Responsible Consumption/Production*, SDG13 *Climate Actions*, and SDG17 *Partnerships for the Goals*.

Guidelines for authors. Authors are encouraged to outline the impacts of waste production, storage, utilization and recycling on the well-being of the human sphere.

Suggested reading. Examples of defining solid waste and solid and hazardous waste [50].

6. Biotechnology towards sustainability

Biotechnology is a powerful tool to replace the products or processes that are harmful to nature. The application of biotechnology towards achieving sustainability is potentially unlimited, but there are few areas where significant advancements have been made through the route of Biotechnology. Biotechnological approaches to attain sustainability fit well with the scope of the journal by having significant contributions towards sustainable biomaterials, food safety, agriculture products and processes. The scope of biotechnology encompasses research on environmental well-being, resource management, alternative energy and waste management. This section focuses on water and energy, which are paramount to attaining a sustainable future, albeit other biotech sustainability research concepts are also within the journal's scope.

Importance of biotechnology towards sustainability. Water scarcity is affecting 40% of the world's population [6] and energy consumption is estimated to increase by 55% by 2030 as an effect of population growth and maintaining higher living standards. Addressing these issues requires a cohort of different approaches and, apart from the strong economic tools, effective policy-making, assessment, strong technological innovations and implementation are of utmost importance. Advanced biotechnology allows for solutions to traditional water and wastewater treatment challenges, such as sludge management, degradation of recalcitrant compounds and biogas production. It promotes sustainable water use, sustainable management of water and sanitation by providing reclaimed water for a variety of purposes [51].

Technological advancements in biotechnology towards sustainability. *Genome editing* is a biotechnological tool through which microcosms can be selected or engineered to purify and remove chemical contaminants from water and soil matrix. In addition, agriculturally important plants can be altered to be drought-resistant, requiring less water. Biotechnology contributes to the energy sector, in the form of bioenergy [46]. The sustainability of this renewable form of energy remains in question, due to the complexity related to deforestation, land use, and associated loss of biodiversity. *Second-generation biofuel* has thus been developed, promoting the use of nonfood crops and waste byproducts for generating bioethanol, biohydrogen, biogas, etc. Microalgae and cyanobacteria have emerged as potential candidates for third-generation biofuel, biochemicals, and other value-added chemicals. In further research advancements, fourth-generation biofuels are now considered by genetically modifying microcosms, with no direct impact on food security and biodiversity [52].

There are many ways biotechnology can pave a path for a sustainable future. Bioprocesses can improve oil refining by omitting undesirable elements/gases [53] and reducing GHG emissions. Biocatalysts can reduce the temperature required for material synthesis, among other examples. Biotechnology finds application in carbon capture and storage, through GHG fixation or mineralization. Moreover, biotechnology provides routes for the identification and production of soil-beneficial microorganisms and biocontrol agents, which are promising routes to reduce fertilizer and pesticide application in agriculture.

However, there are many challenges in terms of scalability, cost, and reproducibility. Having successful application of biotechnology in the attainment of SDGs will need to find a harmony between fundamental research and their possible applications. It will be unrealistic to assume that each problem we try to address can be solved through a biotechnological route, but the integration of some traditional techniques with a biotechnological approach can lead us toward a more sustainable approach to solving problems.

Integration with SDGs. This theme mainly addresses SDGs like *Clean Water and Sanitation* and *Affordable and Clean Energy*.

Guidelines for authors. Authors are encouraged to consider any and all of the sustainable biotechnology concepts that further other SGDs, including bio-packaging, bio-adsorbents for wastewater treatments and similar concepts.

Suggested reading. Environmental sustainability of biochemicals [54].

7. Sustainable energy technologies

Urgent decarbonization, as part of achieving the United Nations' SDGs, requires a dramatic transition of technologies in the energy and transport sectors, to support the integration of renewable energy sources and the electrification of transport. New technologies for sustainability need to be as sustainable as possible, by reducing impacts of resource acquisition, manufacture, recycling and enhancing their performance and length of use as much as possible within these parameters. This section outlines the importance of sustainable energy technologies in the journal's mission and its alignment with the SDGs.

Importance of sustainable energy technologies. The development and deployment of technologies for energy generation, storage and conversion are all important steps towards replacing fossil fuel technologies in global energy and transport systems [55].

Technological advancements in sustainable energy technologies. *Applications for energy technologies*, particularly how they can facilitate efficient production, distribution and use of energy in grids and enable mobility, are the main focus of research in this area. Emerging examples here are hybrid technology solutions and the integration of utility systems. Systems analysis, investigating how and where to deploy and operate these technologies [56], as well as optimizing consumer behavior, are important areas for attention, to ensure the most effective transition to a low-carbon future. *Resource Conservation* focuses primarily on minimizing the depletion of raw materials, with a particular focus on critical minerals [57] but also extends to optimizing water use, avoiding harmful chemicals and reducing waste along the supply chain, particularly the recovery of as many components as possible through effective recycling. Sustainable mining practices are an important emerging field for minimizing the impact on ecosystems and biodiversity during the extraction phase.

Metrics for sustainable energy technologies. The dramatic transition of energy and transport systems will inevitably bring new impacts which also require urgent mitigation. Alongside the reduction of GHG emissions, other impact factors need to be monitored, to avoid replacing one environmental problem with another. This highlights the need for holistic metrics to track life cycle impacts across local and global supply chains [58]. The integration with techno-economic analyses for emerging energy technologies can provide the identification of bottlenecks, fostering awareness about the technological, economic and societal needs for the effective energy transition, from fossil to a truly renewable basis. This is a complex area, as technologies are still evolving and uptake is initially slow, complicating forecasting, but identification of the most impactful life cycle stages or processes is a valuable tool for guiding research.

Integration with SDGs. Sustainable energy technologies aid in achieving numerous SDGs, including *Affordable and Clean Energy* through developing techniques for generating energy from renewable resources and storing that energy effectively to enable mobility and further integration of erratic renewable sources; *Responsible Consumption and Production* through sustainable resource extraction and production methods; *Decent Work and Economic Growth* by ushering in new opportunities for jobs across their supply chains; *Industry, Innovation and Infrastructure* through providing scope for energy and transport systems to be redesigned; *Reduced Inequalities* by enabling greater participation from individuals, communities and countries in generating and controlling their own energy; *Sustainable Cities and Communities* by displacing polluting technologies, leading to improved air quality in cities and by enabling energy and transport to be shared within the urban setting; and *Climate Action* by the displacement of fossil fuels in our energy and transport systems, leading to the reduction of GHG emissions.

Guidelines for authors. Authors are encouraged to illustrate the contribution of their work to the development of sustainable energy technologies, or to the development of metrics and methodologies which assess the sustainability of the technology in its intended application and across its entire lifecycle.

Suggested reading. Innovations in sustainable energy, effective implementation of sustainable energy technologies, and the environmental, social and economic life cycle impacts of these technologies [59].

8. Sustainable chemistry and chemical engineering

Chemistry is a foundational science, underpinning new technologies that are required to reach the United Nations' SDGs through the development of innovative materials and chemical reactions. While chemistry is a molecular science, focusing predominantly on the nanoscale, chemical engineering seeks to bridge chemistry and society, via products, processes, devices and systems. Chemical engineering enables the manufacturing of new materials and products in commercial quantities and allows the implementation of new chemical processes at an industrial scale. A prime target of chemical engineering is to do so safely and in an environmentally responsible way. *Sustainable practices* in chemical production include reusing waste materials to establish a circular economy. Nature offers inspiring examples of zero-waste, circular processes, scalable manufacturing under constraints, and process intensification [60, 61]. Leveraging this, NICE (*nature-inspired chemical engineering*) offers opportunities for sustainability, as a systematic design methodology that seeks inspiration from fundamental mechanisms underpinning desirable properties, such as scalability, efficiency, and resilience, which are equally important in sustainable engineering of processes, products, devices and systems.

Importance of sustainable chemistry and chemical engineering. *Sustainable practices* in chemical production include the development of manufacturing approaches involving reduced energy consumption and GHG emission, utilization of renewable energy and resources, and re-using waste materials to establish a circular economy. Through these activities, chemical industries can enable minimal ecological footprint and pollution, while conserving natural resources, collectively leading to clean air, water, and soil.

Technological advancements in sustainable chemistry and chemical engineering. Developing technologies for sustainable chemical production and waste management is essential to reduce the ecological footprint. Key focus areas encompass *(i) sustainable chemistry routes* that focus on the principles of waste prevention, atom economy, energy efficiency, and the use of renewable feedstocks [62], *(ii) renewable feedstocks and bio-based chemicals*, which not only reduce dependence on fossil fuels but also provide the potential for reduced carbon emissions and improved biodegradability, compared to their petrochemical counterparts [63], *(iii) circular economy and waste valorization* aim to close the loop by promoting resource efficiency, recycling and the recovery of waste and valuable materials [64] and *(iv) process intensification and electrification* [65, 66] such as microreactors, continuous flow processes, integration of reaction and separation processes, and the use of non-thermal energy sources can be employed to enhance energy efficiency and reduce resource consumption in chemical manufacturing.

Integration with SDGs. Chemistry and chemical engineering have both been central to achieving *SDG 2—Zero Hunger*, through the development of fertilizers that sustain Earth's population (without fertilizers, current farming technologies could only sustain *ca*. 4 billion people worldwide) [67]. In the XXI century, chemists work with formulation scientists to develop new herbicides and fungicides, while chemical engineers seek lower-energy routes to large-quantity ammonia production. While fertilizers are indispensable, they do pose a major problem when nitrogen and phosphorus contaminate waterways around farmlands, leading to challenges around *SDG 6—Clean Water and Sanitation*. In addition to sensing and removal of such contaminants from waterways, chemical engineers address SDG 6 through water desalination technologies to produce inexpensive drinking water, removal of microplastics, or the production of high-purity water for electrochemical hydrogen generation. All aspects of the hydrogen economy feed into *SDG 7—Affordable and Clean Energy*. Renewable energy is intermittent by nature, therefore energy generation from these sources must be complemented by robust storage technologies, both stationary and mobile, all of which are bottle-necked by materials challenges, such as cathodes, anodes and membranes for portable batteries, or new redox systems for stationary redox-flow batteries. New materials and new processes are pivotal to reaching other SDGs. Materials for CO_2 capture and economically viable CO_2 conversion processes are crucial for *SDG 13—Climate Action. SDG 12—Responsible Consumption and Production* requires both the development of new biodegradable polymers and chemical methods for the recycling of existing plastic streams, not to mention ethical and economically viable routes to source and recycle critical elements. Finally, *SDG 3—Good Health and Wellbeing* requires a very broad range of innovative products and processes: from new pharmaceuticals to combat antibiotic resistance and clean processes to produce them, through antibacterial and antifungal materials and coatings for medical devices, to chemical sensing methods for early disease diagnosis.

Guidelines for authors. Authors are encouraged to illustrate the contribution of their work to sustainable chemical production and waste management, demonstrating fundamental science, innovative concepts, commercially viable technologies, and new insights into opportunities for multi-disciplinary collaborations.

Practically every paper on applied chemistry can be framed in terms of addressing an SDG. Oftentimes, 'sustainability credentials' are claimed for single-factor improvements, such as working with bio-derived chemicals, or lowering the temperature of a reaction. Entire areas of research, such as catalysis, the use of alternative solvents (ionic liquids or deep eutectic solvents) or mechanochemistry (solvent-free synthesis) are automatically assumed to fall within the remit of 'sustainability' because they can be referred back to the Twelve Principles of Green Chemistry [68, 69].

We look for contributions that—even if they address one specific and narrow problem—place the work in the broad context of whether products, feedstocks and processes fit within the principles of circular economy and sustainability [70]; manuscripts that address a well-defined, real-world need—seek to address policies around the *European Green Deal*, draw from REACH regulations or propose innovative solutions in response to new EPA guidelines. We also encourage meaningful improvements to conventional chemical engineering processes, including the oil and gas sector, that would make them more sustainable, including unconventional synthesis routes of chemicals. In particular, developing alternative synthesis processes or technologies, such as cold plasma-assisted heterogeneous catalytic processing of carbon feedstock highly endothermal reactions, such as methane dry reforming [71] or nitrogen feedstock (ammonia or NO_x synthesis) [72], mechanochemical synthesis of pharmaceutical or agricultural cocrystal materials [73] including understanding the mechanisms, reaction intermediates, complex kinetics and fundamental science guiding scale-up of these unconventional technologies of great emerging sustainable importance.

Beyond clear references to SDGs, we encourage the use of green metrics [62], life cycle analysis and crucially—robust references to benchmarks. This may be a reference to existing industrial processes and their shortcomings in terms of sustainability, or the discussion of alternative approaches reported in the literature.

Finally, a truly sustainable solution is realistic, in terms of economic viability and potential for industrial implementation. To demonstrate this, we encourage interdisciplinary submissions, looking for synergies between chemistry, chemical engineering and material science when combined with techno-economic analysis, supply chain management research, or studies on societal acceptance of technological solutions. The viewpoints and proposed methods, products and technologies from the emerging next-generation scholars are particularly encouraged and their review will be accelerated by the editorial board.

Suggested reading

Twelve principles of green chemistry, green metrics, and sustainable chemical engineering [56, 62, 69].

Next-generation scholars on sustainable process intensification [74].

Closing notes

The ultimate goal of *Sus Sci Tech* is to foster a community of scientists and practitioners that facilitate the understanding, advancement and engagement in sustainable science and technology as a quickly developing field. Authors are encouraged to reach out to the Editor-in-Chief or editorial board to solicit new manuscript or sustainability concept ideas or the ways to present them. We envision updating the scope of the journal annually to maintain and update the vision of sustainable science and technology.

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References

[1] Brundtland G H 1987 Our common future—call for action *Environ. Conserv.* **14** 291–4
[2] Anastas P T and Warner J C 2000 *Green Chemistry: Theory and Practice* (Oxford University Press) p 152
[3] Anastas P T and Zimmerman J B 2003 Peer reviewed: design through the 12 principles of green engineering *Environ. Sci. Technol.* **37** 94A–101A
[4] Mutlu H and Barner L 2022 Getting the terms right: green, sustainable, or circular chemistry? *Macromol. Chem. Phys.* **223** 2200111
[5] Lucas P and Wilting H Using planetary boundaries to support national implementation of environment-related sustainable development goals PBL Netherlands Environmental Assessment Agency; 2018 Sep. Report No.: PBL publication number: 2748
[6] THE 17 GOALS | sustainable development (available at: https://sdgs.un.org/goals) (Accessed 12 January 2024)
[7] Det Udomsap A and Hallinger P 2020 A bibliometric review of research on sustainable construction, 1994–2018 *J. Clean. Prod.* **254** 120073
[8] Ogunmakinde O E, Egbelakin T and Sher W 2022 Contributions of the circular economy to the UN sustainable development goals through sustainable construction *Resour. Conserv. Recycl.* **178** 106023
[9] Lade S J, Steffen W, de Vries W, Carpenter S R, Donges J F, Gerten D, Hoff H, Newbold T, Richardson K and Rockström J 2020 Human impacts on planetary boundaries amplified by Earth system interactions *Nat. Sustain.* **3** 119–28
[10] Steffen W *et al* 2015 Planetary boundaries: guiding human development on a changing planet *Science* **347** 1259855
[11] Fazey I *et al* 2018 Ten essentials for action-oriented and second order energy transitions, transformations and climate change research *Energy Res. Soc. Sci.* **40** 54–70
[12] Al-Saidi M and Elagib N A 2017 Towards understanding the integrative approach of the water, energy and food nexus *Sci. Total Environ.* **574** 1131–9
[13] Nayak S and Iwasa J H 2019 Preparing scientists for a visual future *EMBO Rep.* **20** e49347
[14] Shieber S M 2009 Equity for open-access journal publishing *PLOS Biol.* **7** e1000165
[15] Allen D T, Hwang B-J, Licence P, Pradeep T and Subramaniam B 2015 Advancing the use of sustainability metrics *ACS Sustain. Chem. Eng.* **3** 2359–60
[16] Hernandez A G and Cullen J M 2019 Exergy: a universal metric for measuring resource efficiency to address industrial decarbonisation *Sustain. Prod. Consum.* **20** 151–64
[17] Sikdar S K 2003 Sustainable development and sustainability metrics *AIChE J.* **49** 1928–32
[18] Haddow G and Hammarfelt B 2019 Quality, impact, and quantification: indicators and metrics use by social scientists *J. Assoc. Inf. Sci. Technol.* **70** 16–26
[19] Wiley.com Sustainable Engineering: drivers, Metrics, Tools, and Applications (available at: www.wiley.com/en-us/Sustainable+Engineering%3A+Drivers%2C+Metrics%2C+Tools%2C+and+Applications-p-9781119493938) (Accessed 26 April 2024)
[20] Zulfiqar F, Navarro M, Ashraf M, Akram N A and Munné-Bosch S 2019 Nanofertilizer use for sustainable agriculture: advantages and limitations *Plant Sci.* **289** 110270
[21] Mahanty T, Bhattacharjee S, Goswami M, Bhattacharyya P, Das B, Ghosh A and Tribedi P 2017 Biofertilizers: a potential approach for sustainable agriculture development *Environ. Sci. Pollut. Res.* **24** 3315–35
[22] Zhao G, Zhu X, Zheng G, Meng G, Dong Z and Baek J H 2024 Development of biofertilizers for sustainable agriculture over four decades (1980–2022) *Geogr. Sustain.* **5** 19–28
[23] Mittal D, Kaur G, Singh P, Yadav K and Ali S A Nanoparticle-based sustainable agriculture and food science: recent advances and future outlook *Front. Nanotechnol.* **2** 579954
[24] Sharma R, Kamble S S, Gunasekaran A, Kumar V and Kumar A 2020 A systematic literature review on machine learning applications for sustainable agriculture supply chain performance *Comput. Oper. Res.* **119** 104926
[25] Chlingaryan A, Sukkarieh S and Whelan B 2018 Machine learning approaches for crop yield prediction and nitrogen status estimation in precision agriculture: a review *Comput. Electron. Agric.* **151** 61–69
[26] Raliya R, Saharan V, Dimkpa C and Biswas P Nanofertilizer for precision and sustainable agriculture: current state and future perspectives 2018 *J. Agric. Food Chem.* **66** 6487–503
[27] Lassaletta L, Billen G, Grizzetti B, Anglade J and Garnier J 2014 50 year trends in nitrogen use efficiency of world cropping systems: the relationship between yield and nitrogen input to cropland *Environ. Res. Lett.* **9** 105011
[28] Li S *et al* 2018 Modulating plant growth–metabolism coordination for sustainable agriculture *Nature* **560** 595–600
[29] Basso B and Antle J 2020 Digital agriculture to design sustainable agricultural systems *Nat. Sustain.* **3** 254–6
[30] Walter A, Finger R, Huber R and Buchmann N 2017 Smart farming is key to developing sustainable agriculture *Proc. Natl Acad. Sci.* **114** 6148–50
[31] Lal R 2008 Soils and sustainable agriculture. A review *Agron. Sustain. Dev.* **28** 57–64
[32] Liu M, Chen X and Jiao Y 2024 Sustainable agriculture: theories, methods, practices and policies *Agriculture* **14** 473
[33] Brower-Toland B, Stevens J L, Ralston L, Kosola K and Slewinski T L 2024 A Crucial Role for technology in sustainable agriculture *ACS Agric. Sci. Technol.* **4** 283–91
[34] Zuo K *et al* 2023 Electrified water treatment: fundamentals and roles of electrode materials *Nat. Rev. Mater.* **8** 472–90
[35] Dube N N, ElKady M, Noby H and Nassef M G A 2024 Developing a sustainable grease from jojoba oil with plant waste based nanoadditives for enhancement of rolling bearing performance *Sci. Rep.* **14** 539
[36] Hristea G, Iordoc M, Lungulescu E M, Bejenari I and Volf I 2024 A sustainable bio-based char as emerging electrode material for energy storage applications *Sci. Rep.* **14** 1095
[37] Jabbar A A, Hussain D H, Latif K H, Albukhaty S, Jasim A K, Sulaiman G M and Abomughaid M M 2024 Extremely efficient aerogels of graphene oxide/graphene oxide nanoribbons/sodium alginate for uranium removal from wastewater solution *Sci. Rep.* **14** 1285
[38] Luo Z *et al* 2024 Carbon–carbon bond cleavage for a lignin refinery *Nat. Chem. Eng.* **1** 61–72

[39] Torrente-Murciano L, Dunn J B, Christofides P D, Keasling J D, Glotzer S C, Lee S Y, Van Geem K M, Tom J and He G 2024 The forefront of chemical engineering research *Nat. Chem. Eng.* **1** 18–27

[40] Anacleto T M, Kozlowsky-Suzuki B, Björn A, Yekta S S, Masuda L S M, de Oliveira V P and Enrich-Prast A 2024 Methane yield response to pretreatment is dependent on substrate chemical composition: a meta-analysis on anaerobic digestion systems *Sci. Rep.* **14** 1240

[41] Amin F, Javed M F, Ahmad I, Asad O, Khan N, Khan A B, Ali S, Abdullaev S, Awwad F A and Ismail E A A 2024 Utilization of discarded face masks in combination with recycled concrete aggregate and silica fume for sustainable civil construction projects *Sci. Rep.* **14** 449

[42] Miao Y, Zhao Y, Waterhouse G I N, Shi R, Wu L Z and Zhang T 2023 Photothermal recycling of waste polyolefin plastics into liquid fuels with high selectivity under solvent-free conditions *Nat. Commun.* **14** 4242

[43] Hu Z, Li L, Cen X, Zheng M, Hu S, Wang X, Song Y, Xu K and Yuan Z 2023 Integrated urban water management by coupling iron salt production and application with biogas upgrading *Nat. Commun.* **14** 6405

[44] Huang X, Guida S, Jefferson B and Soares A 2020 Economic evaluation of ion-exchange processes for nutrient removal and recovery from municipal wastewater *npj Clean Water* **3** 1–10

[45] Liu Q, Wu L, Jackstell R and Beller M 2023 Using carbon dioxide as a building block in organic synthesis *Nat. Commun.* **6** 5933

[46] Pan Y *et al* 2023 Renewable formate from sunlight, biomass and carbon dioxide in a photoelectrochemical cell *Nat. Commun.* **14** 1013

[47] Gómez-Sanabria A, Kiesewetter G, Klimont Z, Schoepp W and Haberl H 2022 Potential for future reductions of global GHG and air pollutants from circular waste management systems *Nat. Commun.* **13** 106

[48] Zhou J, Wu Z, Jin C and Zhang J X J 2024 Machine learning assisted dual-functional nanophotonic sensor for organic pollutant detection and degradation in water *npj Clean Water* **7** 1–11

[49] Akbarifard S, Madadi M R and Zounemat-Kermani M 2024 An artificial intelligence-based model for optimal conjunctive operation of surface and groundwater resources *Nat. Commun.* **15** 553

[50] US EPA O 2016 Criteria for the definition of solid waste and solid and hazardous waste exclusions (available at: www.epa.gov/hw/criteria-definition-solid-waste-and-solid-and-hazardous-waste-exclusions) (Accessed 26 April 2024)

[51] Gavrilescu M and Chisti Y 2005 Biotechnology—a sustainable alternative for chemical industry *Biotechnol. Adv.* **23** 471–99

[52] Alalwan H A, Alminshid A H and Aljaafari H A S 2009 Promising evolution of biofuel generations. Subject review *Renew. Energy Focus* **28** 127–39

[53] Kilbane J J Future applications of biotechnology to the energy industry 2016 *Front. Microbiol.* **7** 162409

[54] Ögmundarson Ó, Herrgård M J, Forster J, Hauschild M Z and Fantke P 2020 Addressing environmental sustainability of biochemicals *Nat. Sustain.* **3** 167–74

[55] Markard J 2018 The next phase of the energy transition and its implications for research and policy *Nat. Energy* **3** 628–33

[56] Tovar-Facio J, Martín M and Ponce-Ortega J M 2021 Sustainable energy transition: modeling and optimization *Curr. Opin. Chem. Eng.* **31** 100661

[57] Pommeret A, Ricci F and Schubert K 2022 Critical raw materials for the energy transition *Eur. Econ. Rev.* **141** 103991

[58] Campos-Guzmán V, García-Cáscales M S, Espinosa N and Urbina A 2019 Life cycle analysis with multi-criteria decision making: a review of approaches for the sustainability evaluation of renewable energy technologies *Renew. Sustain. Energy Rev.* **104** 343–66

[59] Santoyo-Castelazo E and Azapagic A 2014 Sustainability assessment of energy systems: integrating environmental, economic and social aspects *J. Clean. Prod.* **80** 119–38

[60] Coppens M O 2021 Nature-inspired chemical engineering for process intensification *Annu. Rev. Chem. Biomol.* **12** 187–215

[61] Trogadas P and Coppens M O 2020 Nature-inspired chemical engineering: a new design methodology for sustainability *Sustainable Nanoscale Engineering* ed G Szekely and A Livingston (Elsevier) (ch 2 available at: www.sciencedirect.com/science/article/pii/B9780128146811000023)

[62] Sheldon R A 2018 Metrics of green chemistry and sustainability: past, present, and future *ACS Sustain. Chem. Eng.* **6** 32–48

[63] Escobar N and Laibach N 2021 Sustainability check for bio-based technologies: a review of process-based and life cycle approaches *Renew. Sustain. Energy Rev.* **135** 110213

[64] Bigdeloo M, Teymourian T, Kowsari E, Ramakrishna S and Ehsani A 2021 Sustainability and circular economy of food wastes: waste reduction strategies, higher recycling methods, and improved valorization *Mater. Circ. Econ.* **3** 3

[65] Chen T Y, Hsiao Y W, Baker-Fales M, Cameli F, Dimitrakellis P and Vlachos D G 2022 Microflow chemistry and its electrification for sustainable chemical manufacturing *Chem. Sci.* **13** 10644–85

[66] Ramírez-Márquez C, Al-Thubaiti M M, Martín M, El-Halwagi M M and Ponce-Ortega J M 2023 Processes intensification for sustainability: prospects and opportunities *Ind. Eng. Chem. Res.* **62** 2428–43

[67] Erisman J W, Sutton M A, Galloway J, Klimont Z and Winiwarter W 2008 How a century of ammonia synthesis changed the world *Nat. Geosci.* **1** 636–9

[68] Lane M K M *et al* 2023 Green chemistry as just chemistry *Nat. Sustain.* **6** 502–12

[69] Krasnodębski M 2024 The bumpy road to sustainability: reassessing the history of the twelve principles of green chemistry *Stud. Hist. Phil. Sci.* **103** 85–94

[70] Zimmerman J B, Anastas P T, Erythropel H C and Leitner W 2020 Designing for a green chemistry future *Science* **367** 397–400

[71] Nozaki T and Okazaki K 2013 Non-thermal plasma catalysis of methane: principles, energy efficiency, and applications *Catal. Today* **211** 29–38

[72] Rouwenhorst K H R, Jardali F, Bogaerts A and Lefferts L 2021 From the Birkeland–Eyde process towards energy-efficient plasma-based NOX synthesis: a techno-economic analysis *Energy Environ. Sci.* **14** 2520–34

[73] Brekalo I *et al* 2022 Scale-up of agrochemical urea-gypsum cocrystal synthesis using thermally controlled mechanochemistry *ACS Sustain. Chem. Eng.* **10** 6743–54

[74] Patrascu M, Vilé G, Xiong Q, Bracconi M, Pinjari D V and Coppens M O 2023 Editorial: voices of the next generation of process intensification *Chem. Eng. Process.—Process Intensif.* **191** 109445